The trajectory of interstellar visitor `Oumuamua

Credits: ESO/M. Kornmesser

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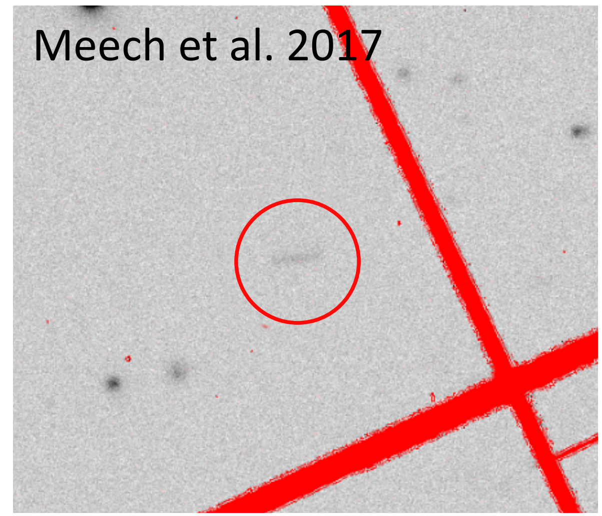
Discovery on Oct. 19

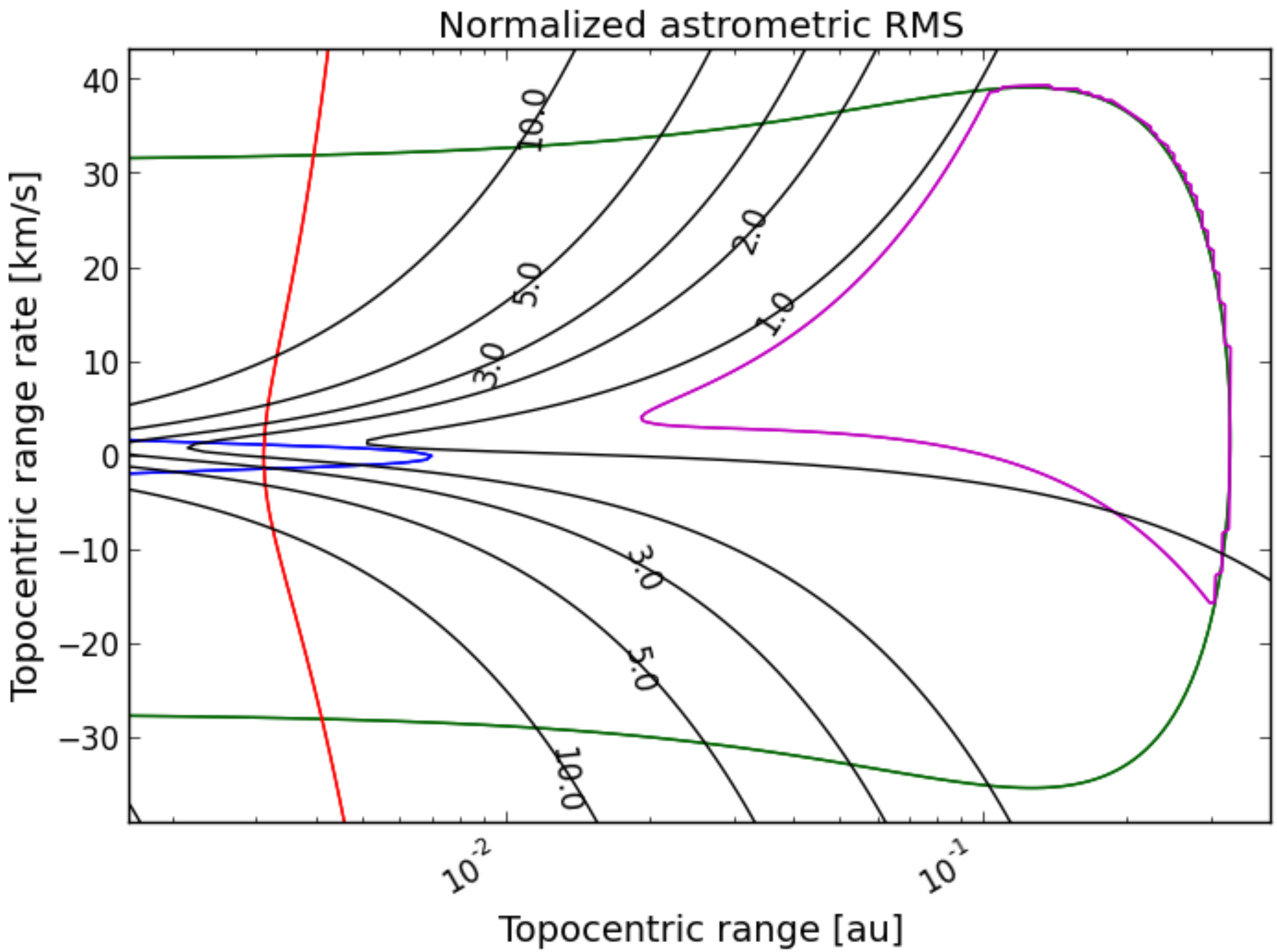
Pan-STARRS 1



NEOCP as P10Ee5V

Four observations, V = 20, plane-of-sky rate of motion 0.25”/s

Initial orbit determination

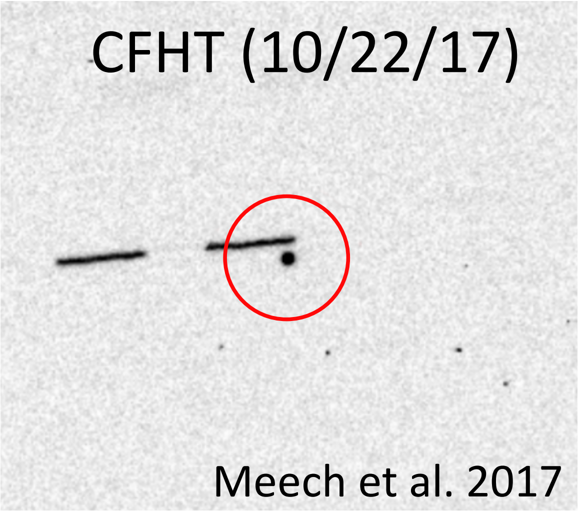


Follow-up

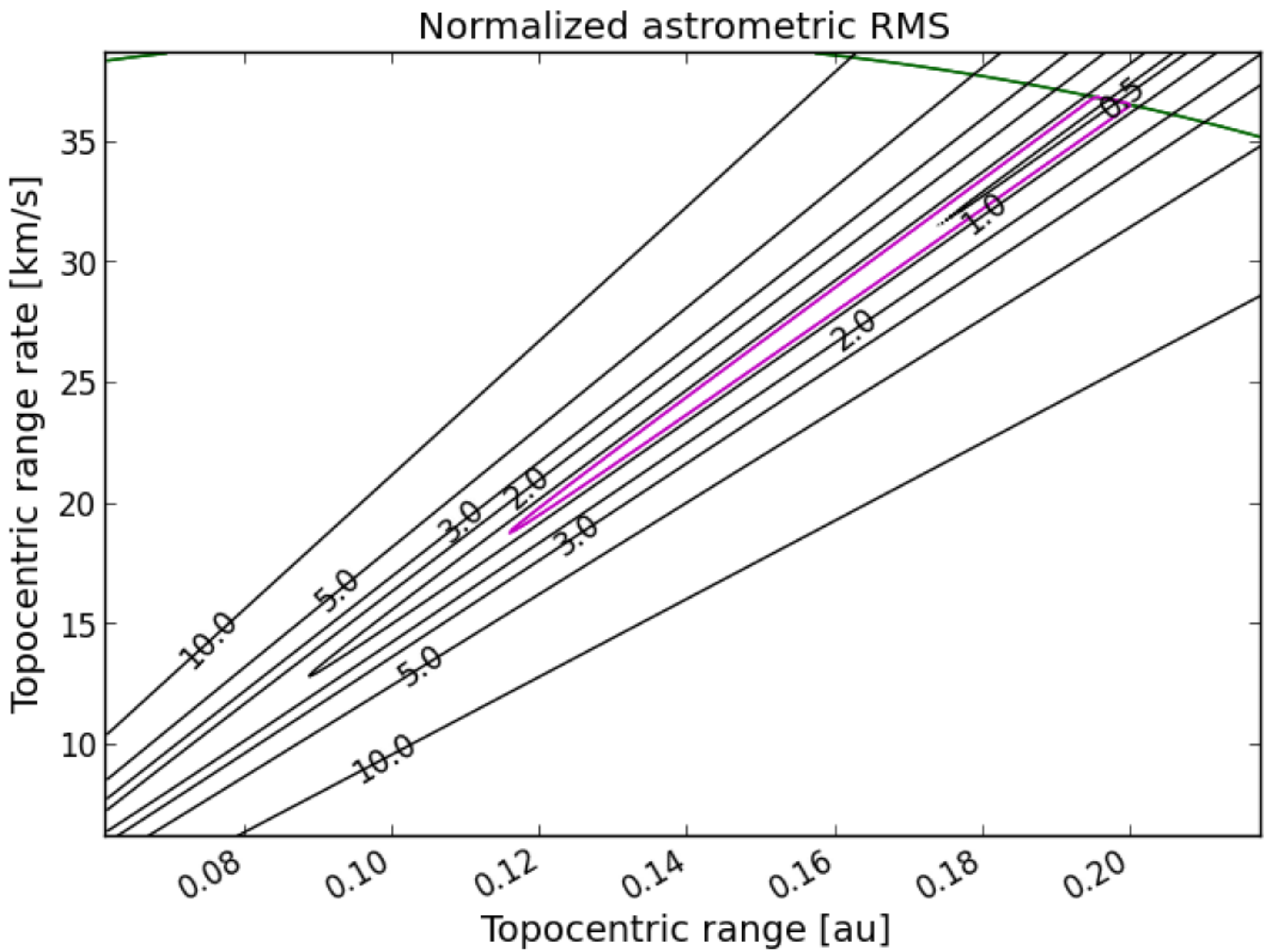
Within few days, many other stations observed P10Ee5V
The Catalina Sky Survey provided precoveries as early as Oct. 14

ESA OGS (1m)

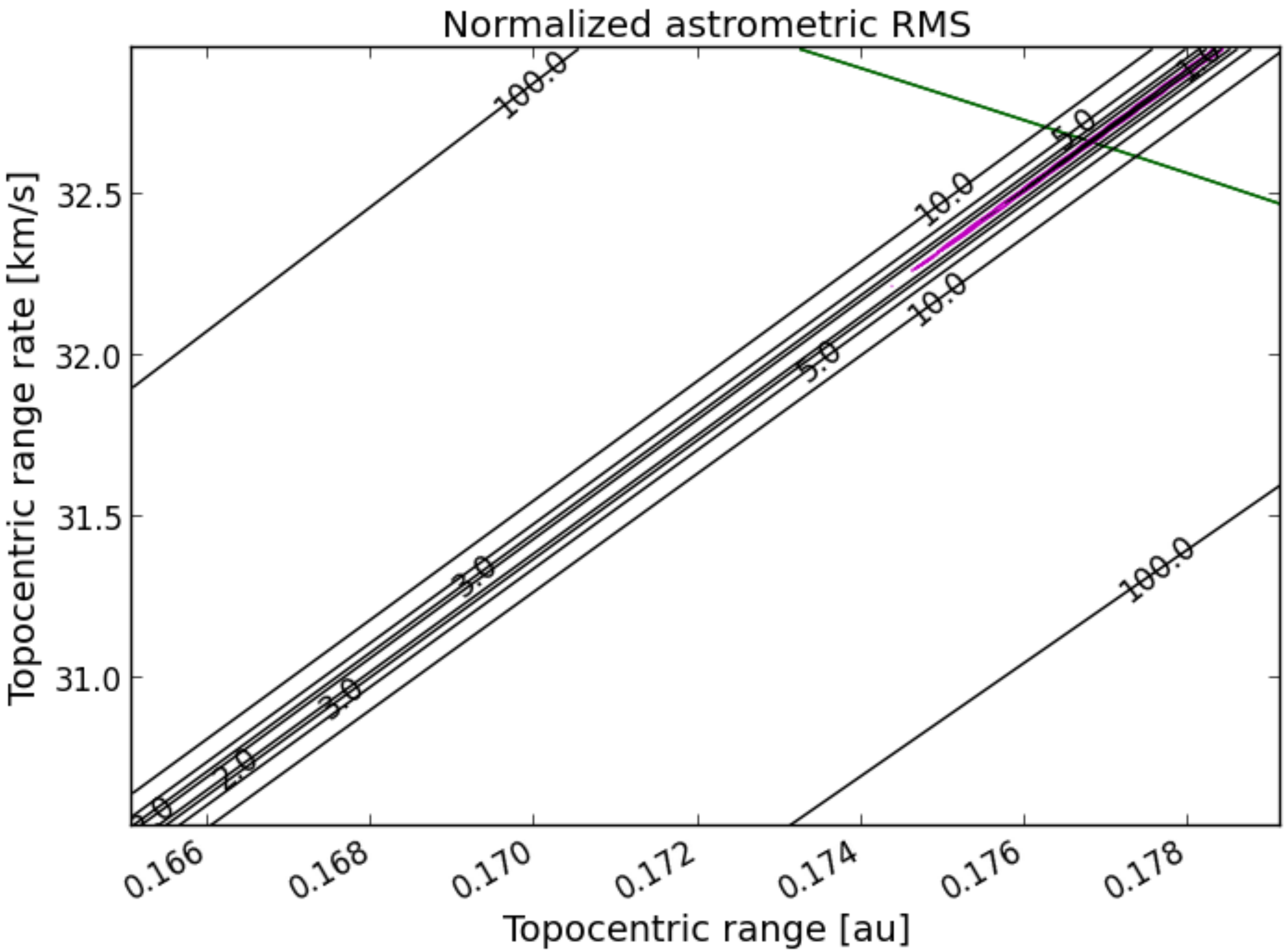
CFHT



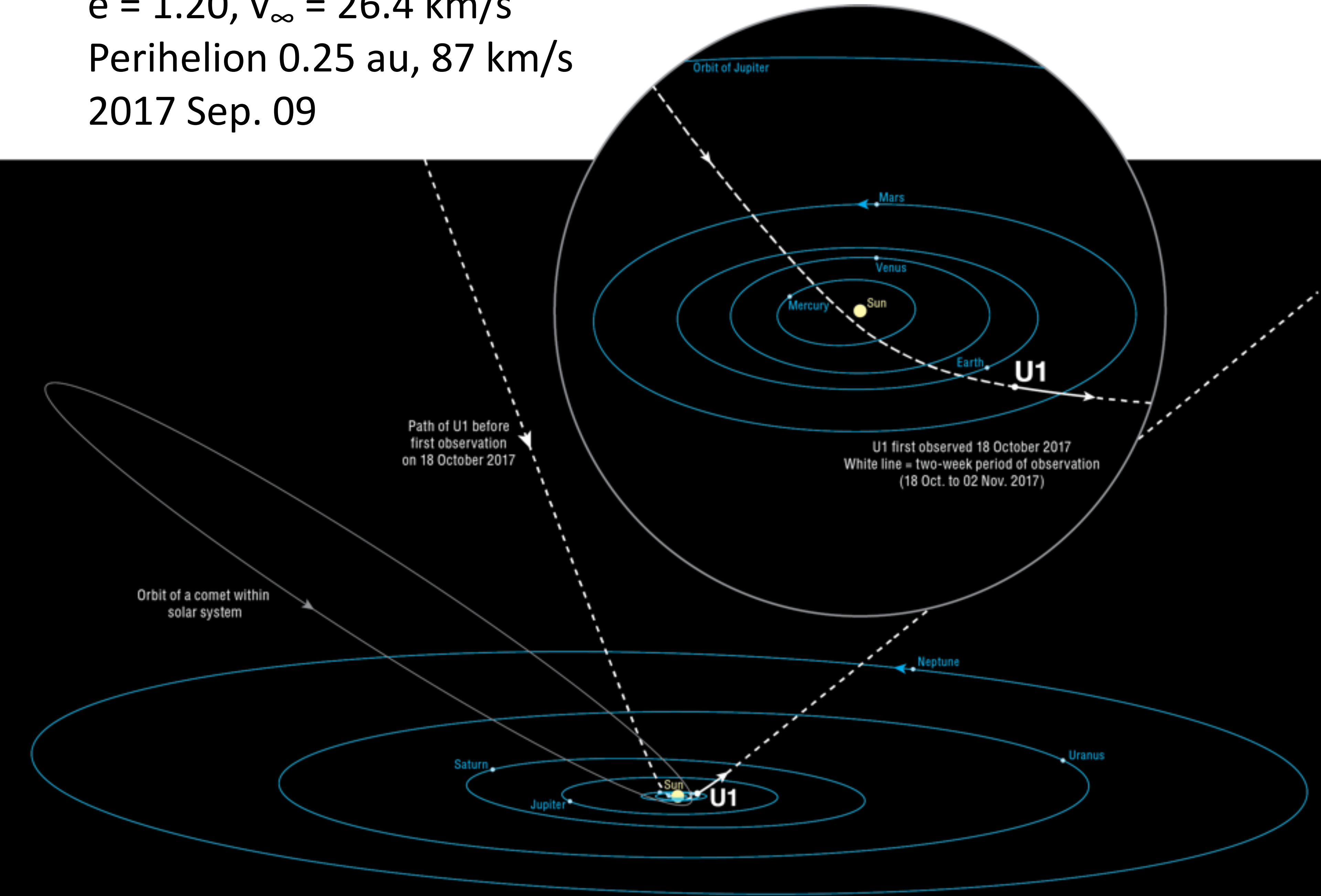
Updated orbit determination



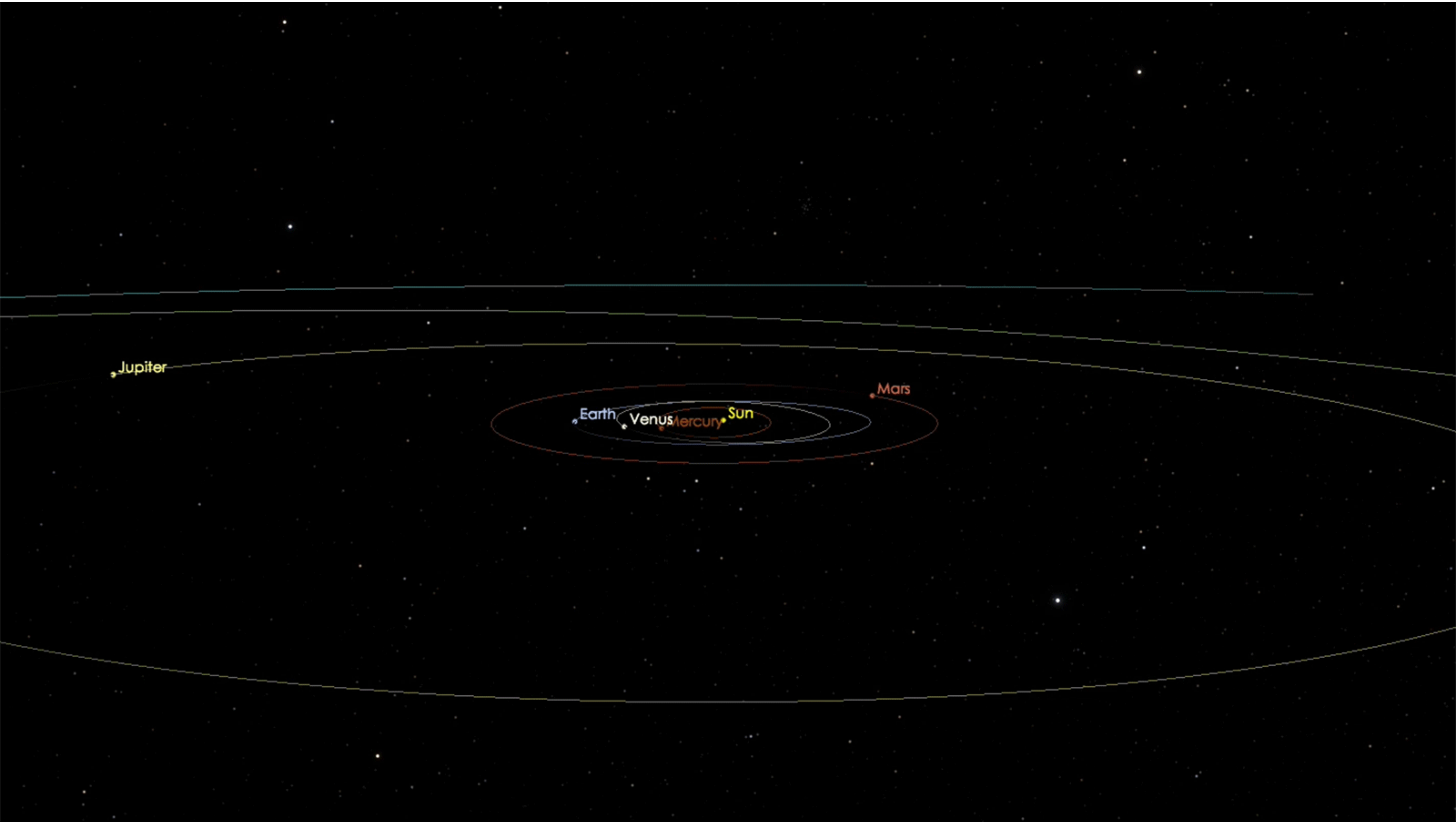
Updated orbit determination



$e = 1.20$, $v_\infty = 26.4$ km/s
Perihelion 0.25 au, 87 km/s
2017 Sep. 09



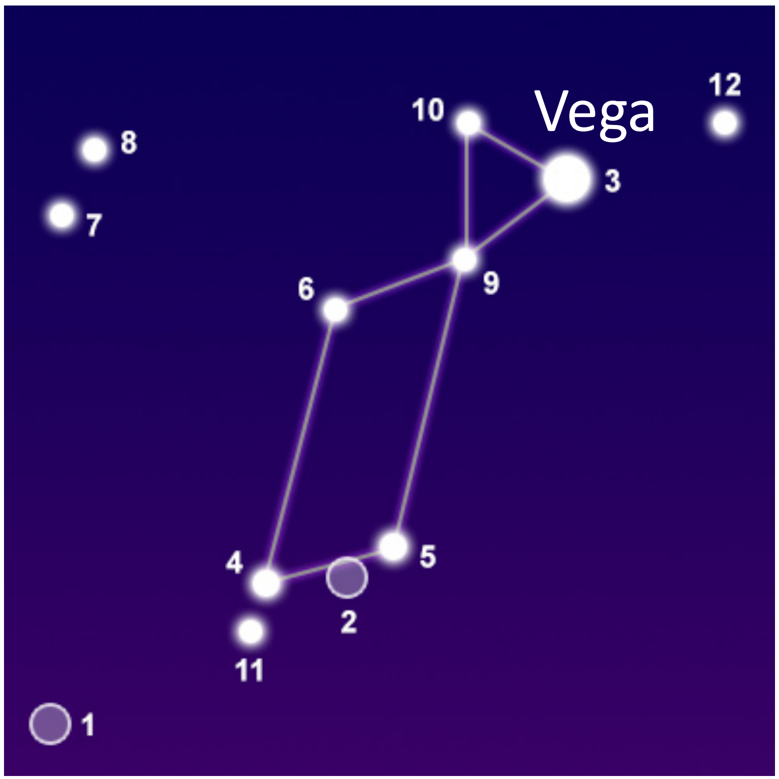
ESO/K. Meech et al.



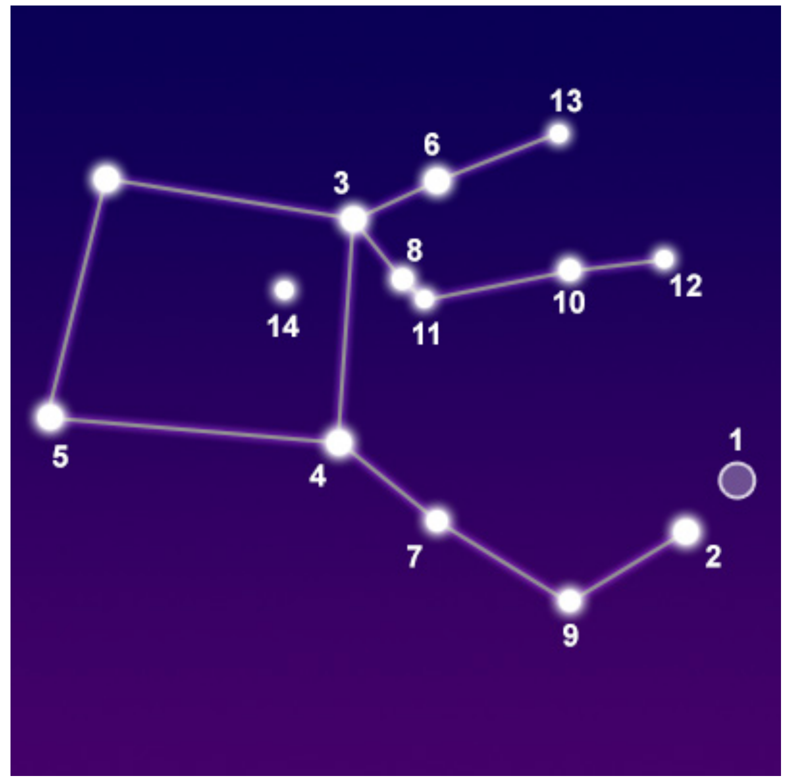
Earth close approach on Oct 14 at 0.16 au, relative velocity 60 km/s

Where from and to?

Inbound direction: Lyra
(RA, Dec) = (279°, 34°)



Outbound direction: Pegasus
(RA, Dec) = (358°, 25°)

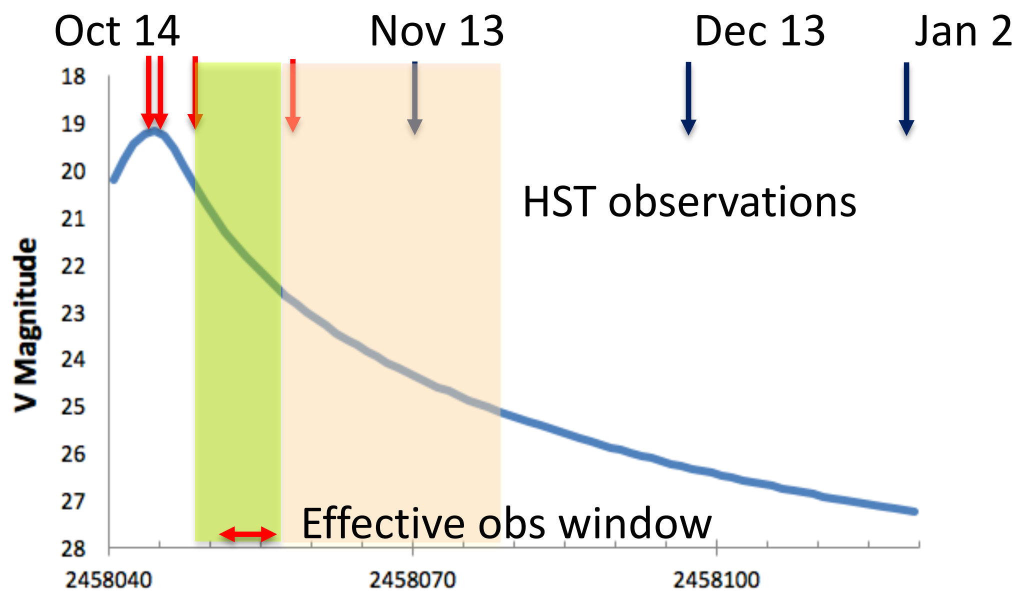


MPC announcement(s)

- Oct. 25 03:53, MPEC 2017-U181: C/2017 U1
  - "Unless there are serious problems with much of the astrometry listed below, strongly hyperbolic orbits are the only viable solutions."
- Oct. 25 22:22, MPEC 2017-U183: A/2017 U1
  - "in a very deep stacked image, obtained with the VLT, this object appears completely stellar"
- Nov. 06, MPEC 2017-V17: 1I/`Oumuamua
  - "The name, which was chosen by the Pan-STARRS team, is of Hawaiian origin and reflects the way this object is like a scout or messenger sent from the distant past to reach out to us"

Timeline

- Size & shape, mass, density
- Rotation period
- Composition
  - Color, spectral features?
  - Comet or asteroid?
  - Gas chemistry?
- Orbit
- Origin & implications



Meech 2018

PI	Telescope	Allocation	Date Obs	Science
Hainaut/Meech	VLT 8m	3.5 hr	10/25, 10/26	Rotation, shape, color
Fitzsimmons	WHT	< 1 hr	10/25, 10/28	Spectrum
Masiero	Palomar 5m	3 hr	10/25	Spectrum
Ye	Palomar 5m	< 1 hr	10/26	Spectrum
Meech	Gemini 8m	3.5 hr	10/26, 10/27	Rotation, shape, color
Snodgrass	VLT 8m	4 hr	10/27	Spectrum
Guzik	Gemini 8m	9.7 hr	10/27	Rotation
Chambers	UKIRT 3.8 m	9 hr	10/27, 10/28	Color - IR
Magnier	Keck 10 m	3 hr	10/27	Rotation, color
Wainscoat	CFHT 3.6 m	8 hr	10/27, 11/20, 11/21	Rotation, astrometry
Jewitt	NOT 2.5 m	2.3 hr	10/25, 10/30	Rotation, color
Jewitt	WIYN 3.5m	4.5 hr	10/28	Rotation
Bannister	Gemini 8 m	2 hr	10/29	Colors
Bolin	APO 3.5m	4 hr	10/29	Rotation
Knight	DCT 4 m	2.8 hr	10/30	Rotation
Meech	HST 1.8 m	9 orbits	11/21, 11/22, Dec, Jan	Astrometry
Sheppard	Magellan 6.5m	3 hr	11/21, 11/22	Rotation
Trilling	Spitzer	32.6 hr	11/21	Albedo, size

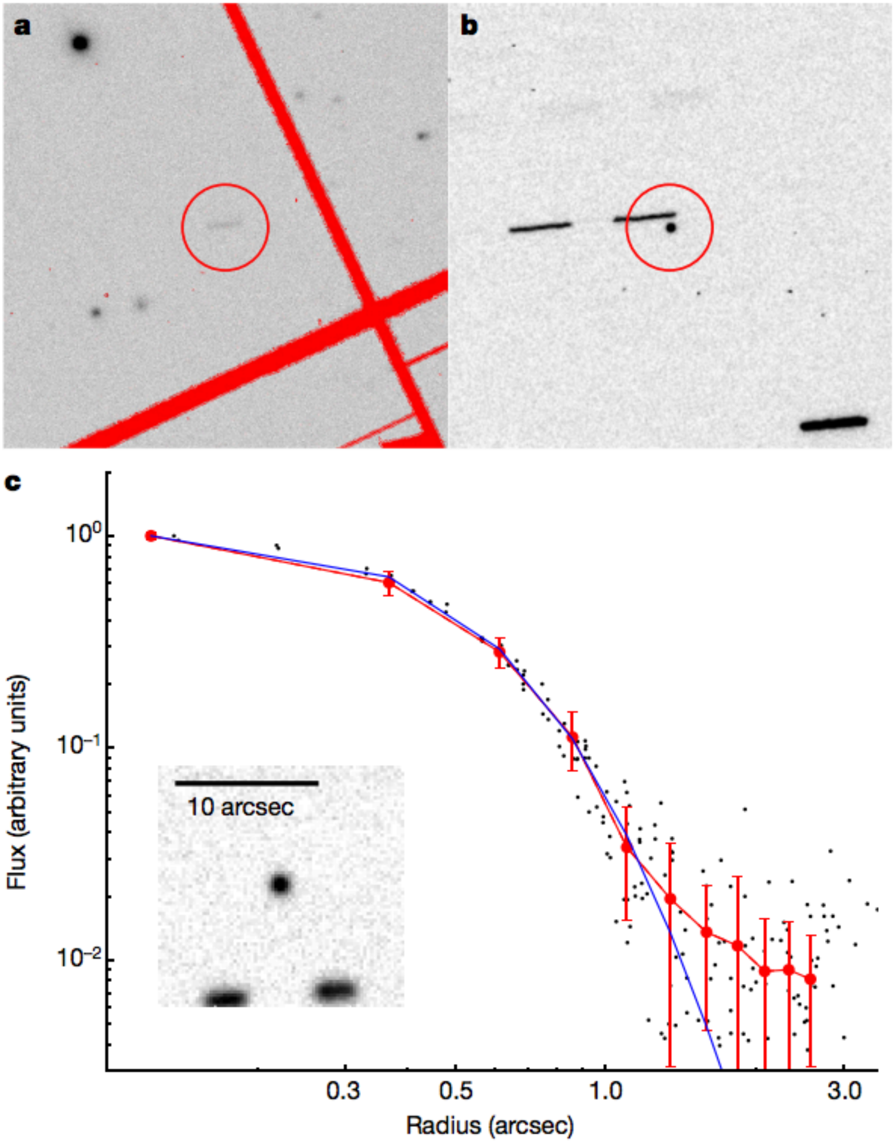
Meech 2018

43 papers as of July 2018

1	2018MNRAS.479L..17P	1.000	09/2018	A	E F	X		R C	U
	Portegies Zwart, Simon; Torres, Santiago; Pelupessy, Inti; Bédorf, Jeroen; Cai, Maxwell X.	The origin of interstellar asteroidal objects like 1I/2017 U1 `Oumuamua							
2	2018Icar..311..170K	1.000	09/2018	A	E			R	U
	Kwiecinski, James A.; Krause, Andrew L.; Van Gorder, Robert A.	Effects of tidal torques on 1I/2017 U1 ('Oumuamua)							
3	2018PASJ...70...80T	1.000	08/2018	A	E F	X		R C	U
	Tanikawa, Ataru; Suzuki, Takeru K.; Doi, Yasuo	Metal pollution of low-mass Population III stars through accretion of interstellar objects like `Oumuamua							
4	2018MNRAS.tmp.2101A	1.000	08/2018	A	E	X		R	U
	Almeida-Fernandes, F.; Rocha-Pinto, H. J.	A kinematical age for the interstellar object 1I/'Oumuamua							
5	2018MNRAS.478L..95K	1.000	07/2018	A	E F	X		R C	U
	Katz, J. I.	Why is interstellar object 1I/2017 U1 (`Oumuamua) rocky, tumbling and possibly very prolate?							
6	2018MNRAS.478L..49J	1.000	07/2018	A	E F	X		R C	U
	Jackson, Alan P.; Tamayo, Daniel; Hammond, Noah; Ali-Dib, Mohamad; Rein, Hanno	Ejection of rocky and icy material from binary star systems: implications for the origin and composition of 1I/`Oumuamua							
7	2018MNRAS.477.5692G	1.000	07/2018	A	E F	X		R C	U
	Gaidos, E.	What and whence 1I/`Oumuamua: a contact binary from the debris of a young planetary system?							
8	2018ApJ...861...35R	1.000	07/2018	A	E F	X		R C	U
	Rafikov, Roman R.	1I/2017 'Oumuamua-like Interstellar Asteroids as Possible Messengers from Dead Stars							
9	2018Natur.559..223M	1.000	06/2018	A	E		D	R C	U
	Micheli, Marco; Farnocchia, Davide; Meech, Karen J.; Buie, Marc W.; Hainaut, Olivier R.; Prialnik, Dina; Schörghofer, Norbert; Weaver, Harold A.; Chodas, Paul W.; Kleyna, Jan T.; and 7 coauthors	Non-gravitational acceleration in the trajectory of 1I/2017 U1 ('Oumuamua)							
10	2018MNRAS.477L..85J	1.000	06/2018	A				R C	U
	Jackson, Alan P.; Tamayo, Daniel; Hammond, Noah; Ali-Dib, Mohamad; Rein, Hanno	Ejection of rocky and icy material from binary star systems: implications for the origin and composition of 1I/`Oumuamua							

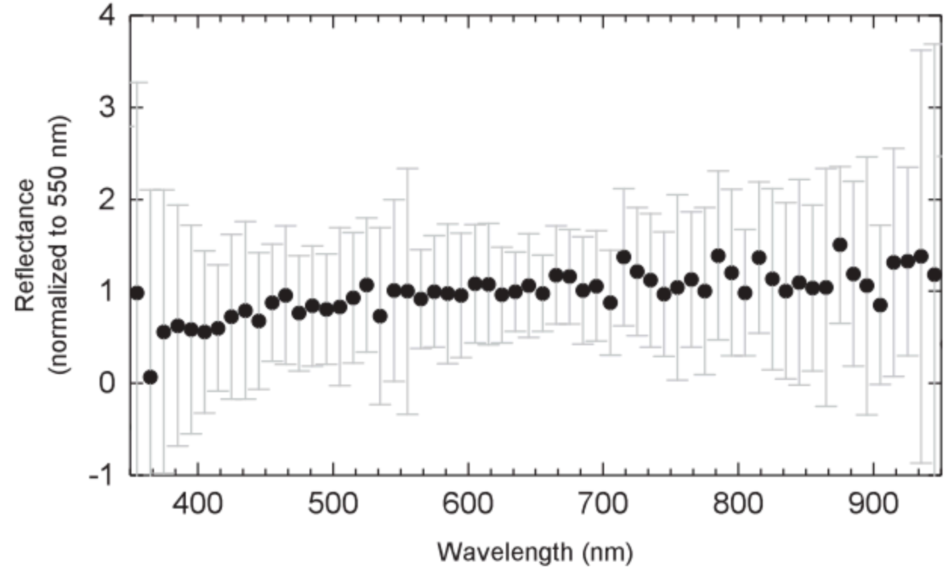
Asteroid or comet?

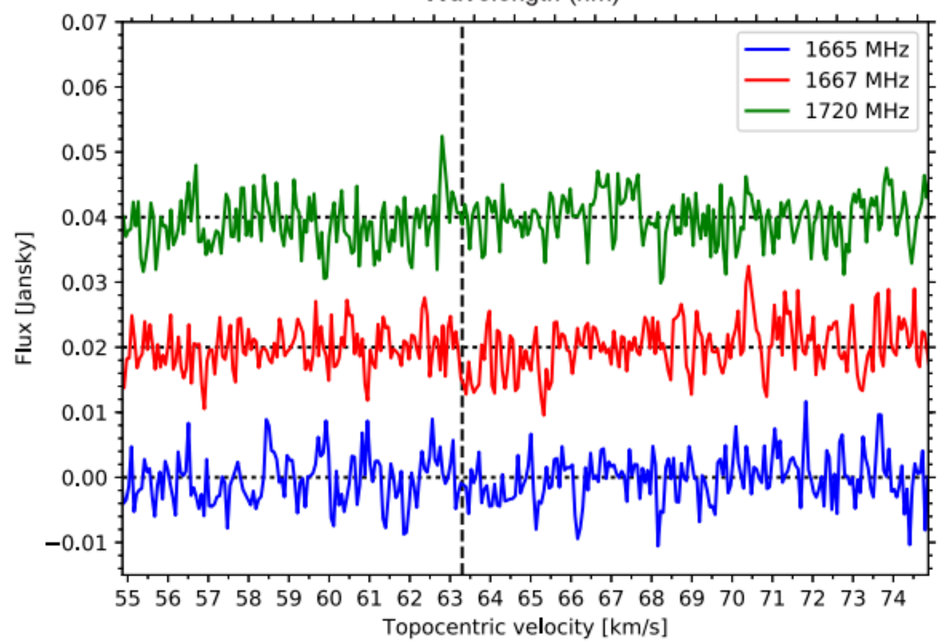
- Meech et al. 2017:
  - "Our observations ... reveal it to be asteroidal, with no hint of cometary activity"
- Jewitt et al. 2017:
  - "The absence of coma shows that the surface of U1 contains little ice. However, we cannot conclude that U1 is an asteroid"



Asteroid or comet?

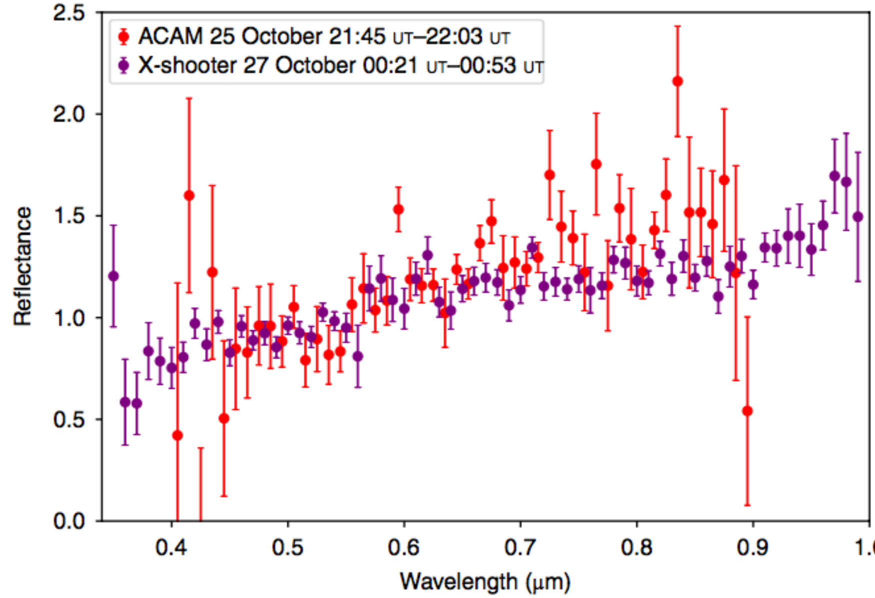
- Ye et al. 2017:
  - Spectroscopy and imaging with Canadian Meteor Orbit Radar
  - Q[CN] < 2×10^{22} mol/s
    Q[H2O] < $2 \times 10^{24-25}$ mol/s
- Park et al. 2018:
  - Search for OH 18 cm radio emission with Green Bank Telescope
  - Q[OH] < 0.17×10^{28} mol/s



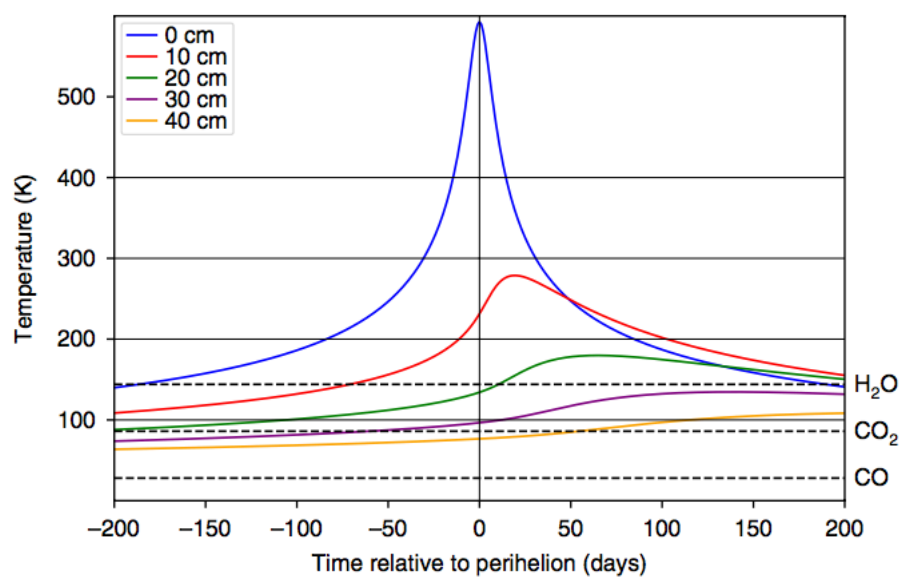


Asteroid or comet?

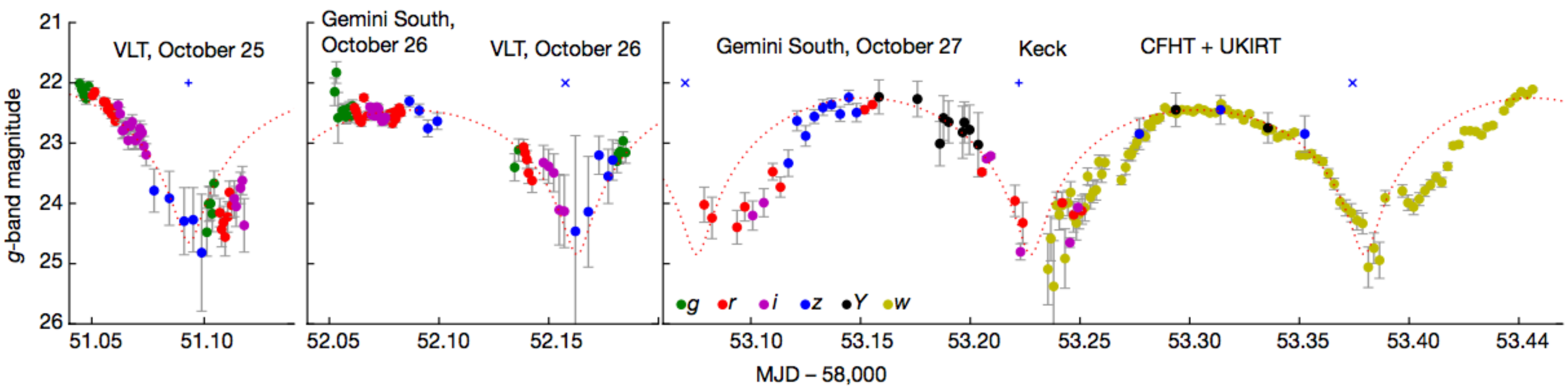
- Fitzsimmons et al. 2017:
  - "interstellar population dominated by comet-like bodies"
  - Color consistent with a comet
  - "insulating mantle due to long-term cosmic ray exposure"



- Raymond et al. 2018:
  - "an extinct fragment of a comet-like planetesimal"
  - "parent underwent a close encounter with a giant planet and was tidally disrupted"



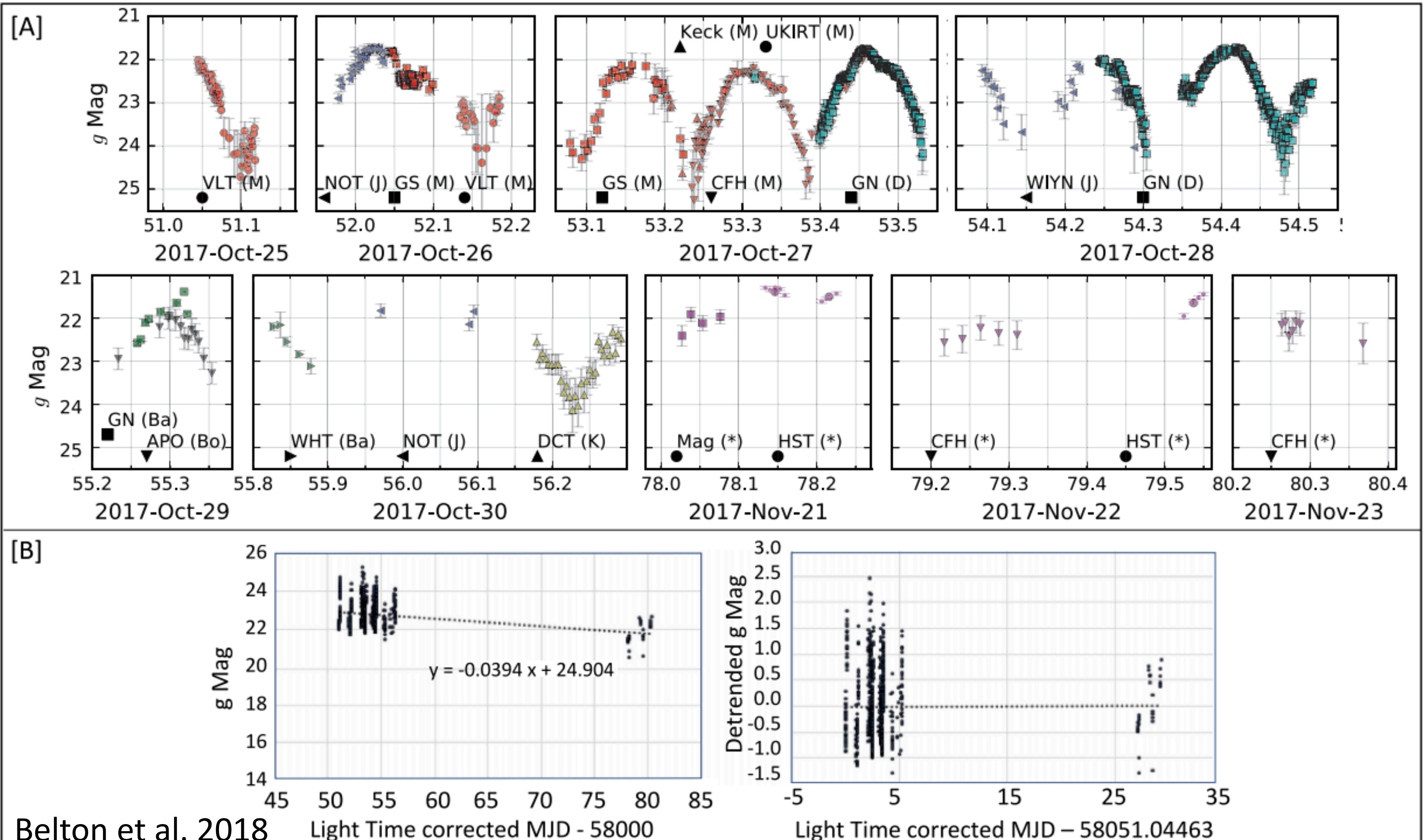
Photometry



Meech et al. 2017:

- H = 22.4
- Large magnitude variations, axis ration ~ 10:1
- Rotation period: 7.34 h
- Effective diameter 200 m for 0.04 albedo

Complex rotation: 8.7 and 3.7 h periods



Belton et al. 2018

Elongated shape

Axis ratio

Meech et al. 2017: 10:1

Jewitt et al. 2017: >6:1

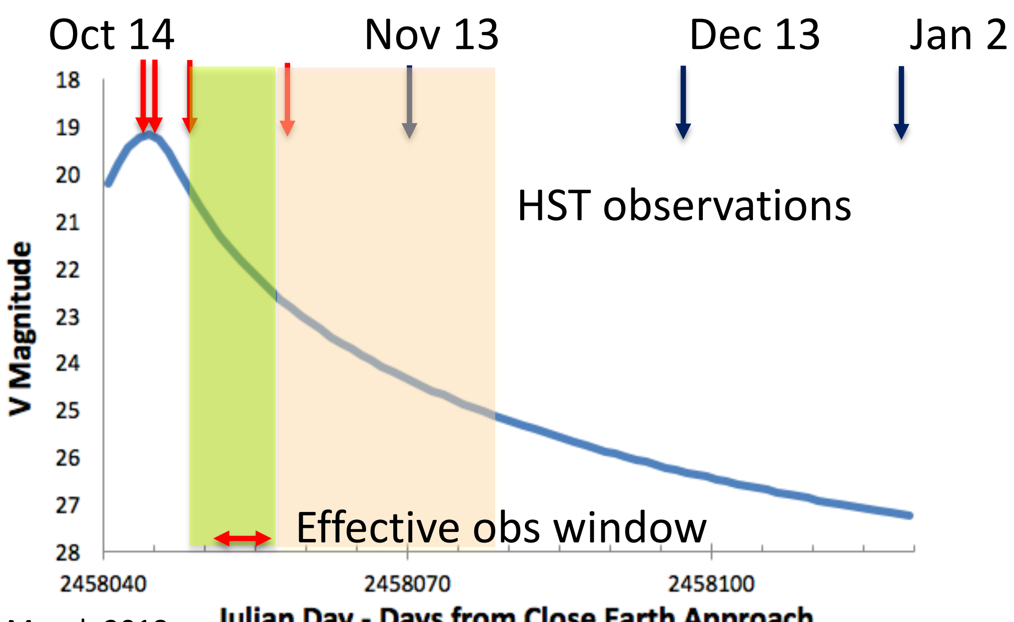
Knight et al. 2017: >3:1

Bolin et al. 2017: >3.5:1

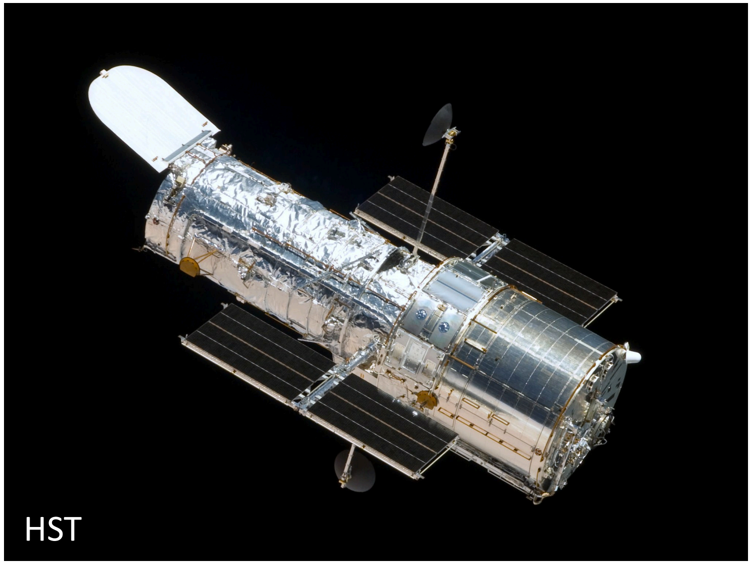
Belton et al. 2018: “`Oumuamua is "cigar-shaped," if close to its lowest rotational energy, and an extremely oblate spheroid if close to its highest energy state”

Where did it come from?

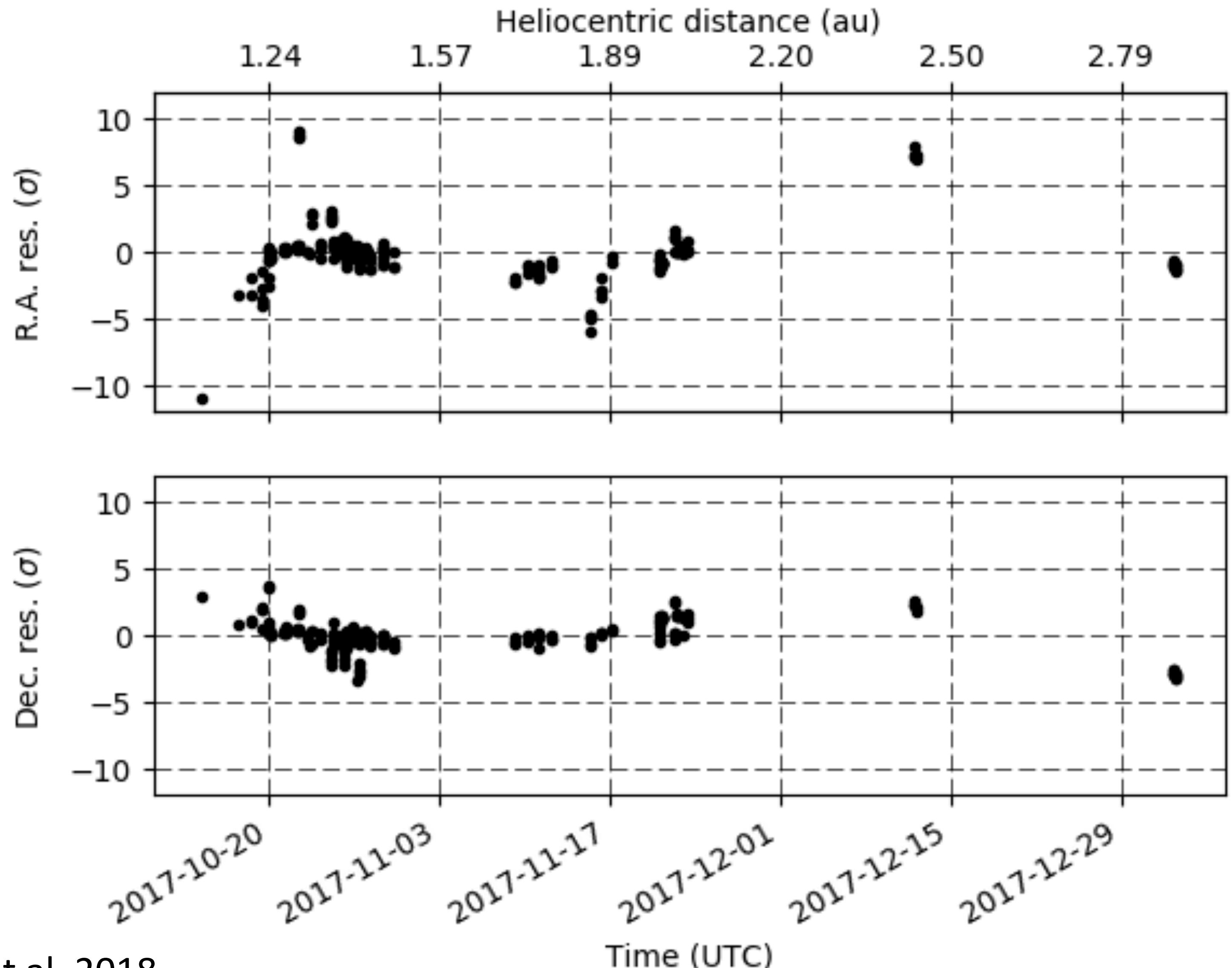
Orbit improvement
Arc extension



Meech 2018

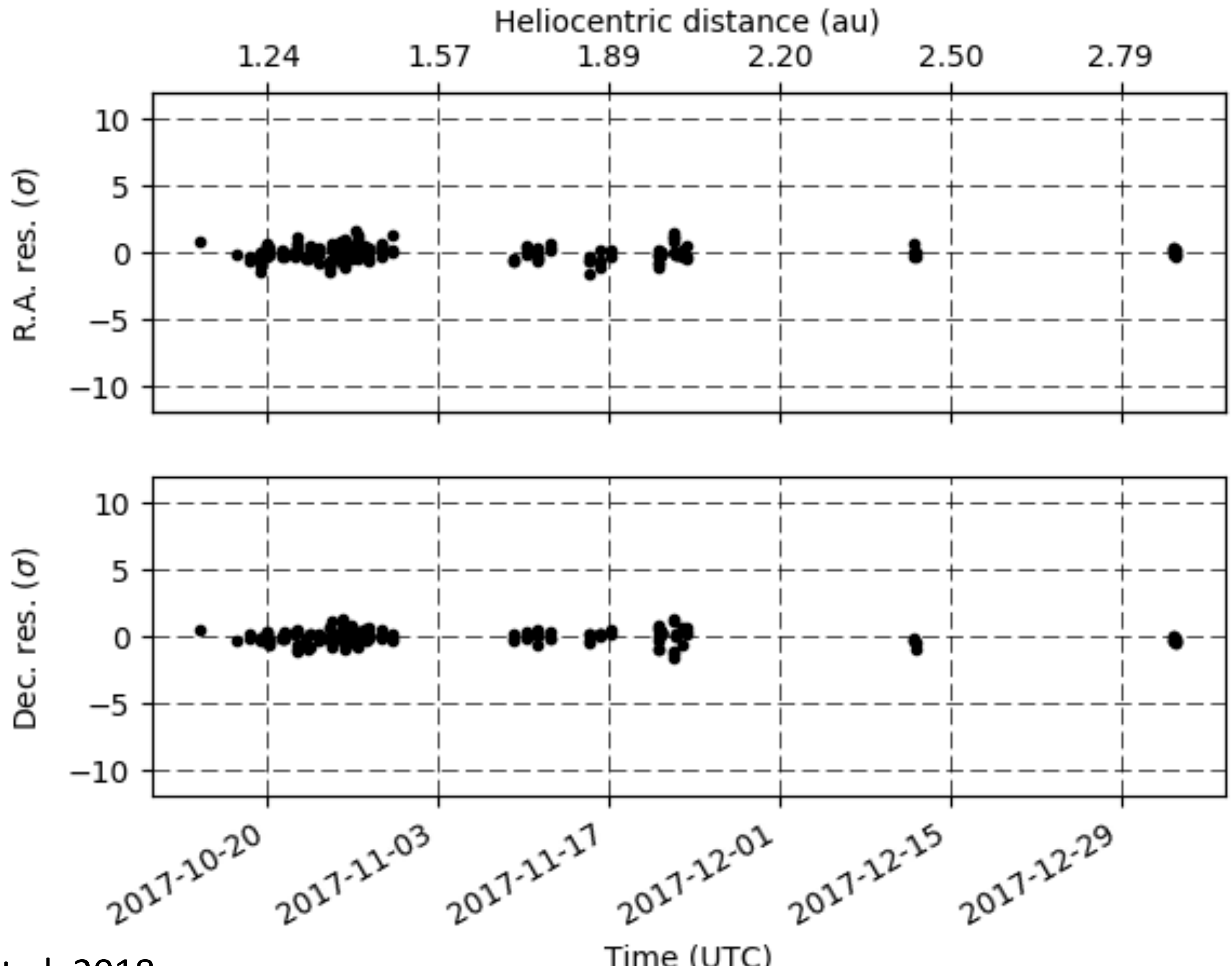


Can’t fit the data!

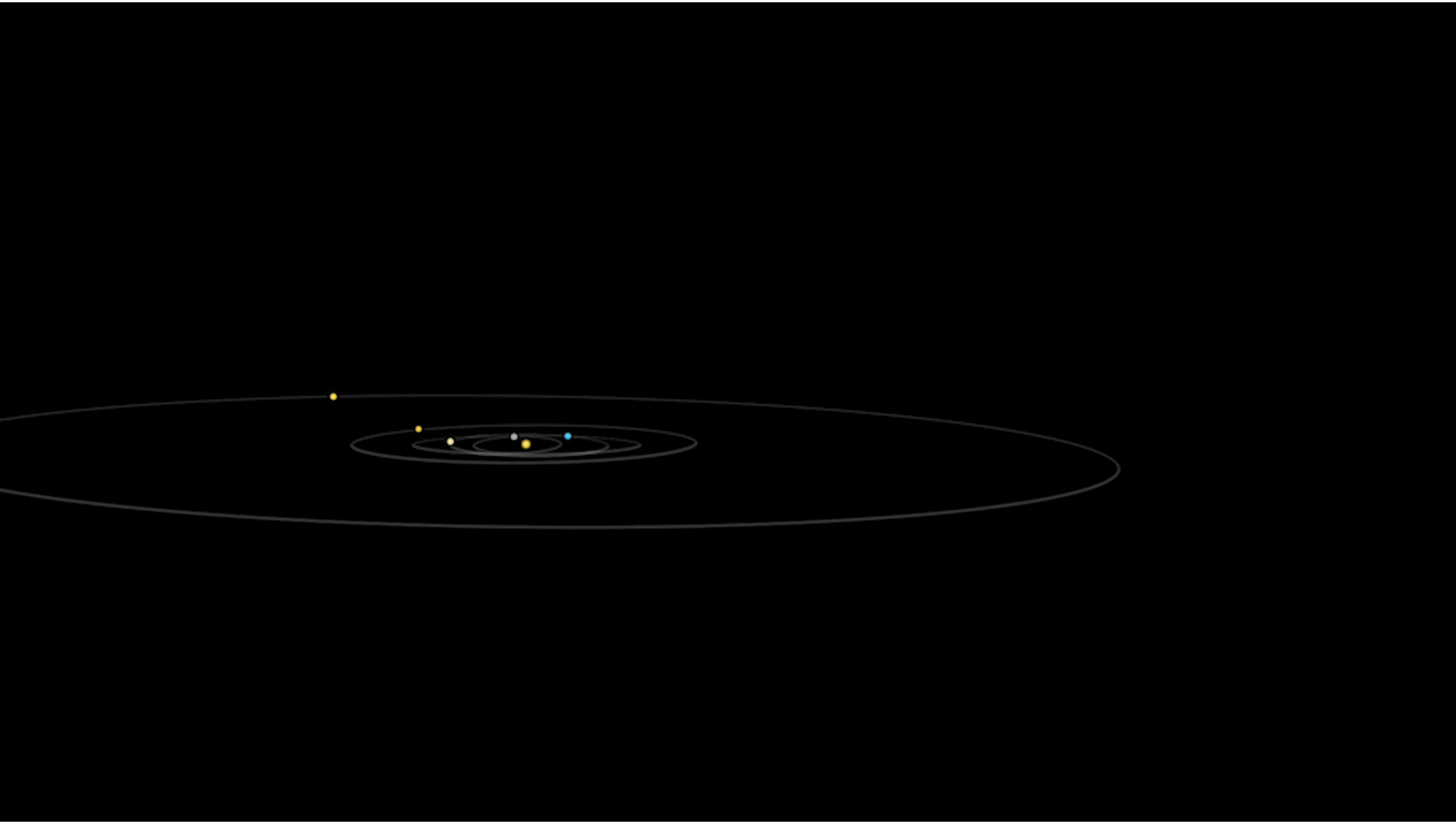


Micheli et al. 2018

Nongravitational acceleration, 30σ



Micheli et al. 2018



What causes it?

Radial acceleration ~ $1/r^2$

About 0.1% of Sun’s gravity

- Cometary outgassing
- Solar radiation pressure
- Yarkovsky effect
- Impulsive Δv
- Photometric offsets
- Binary
- Friction like acceleration
- Magnetized object

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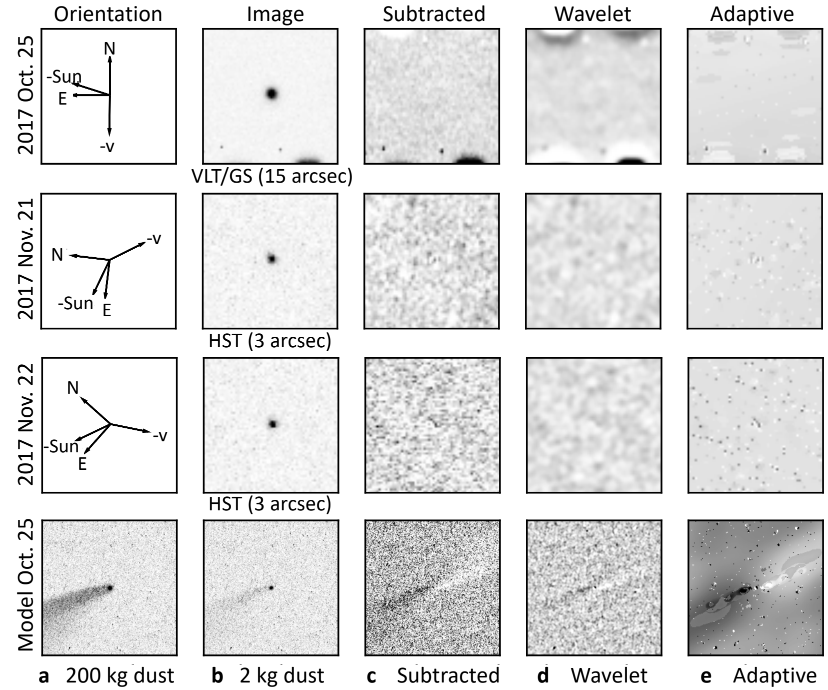
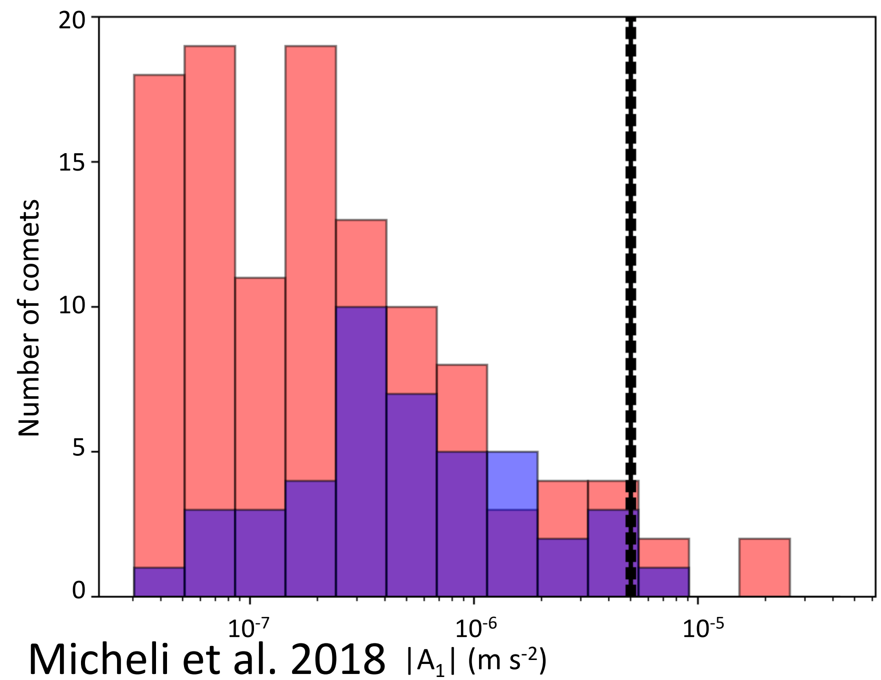
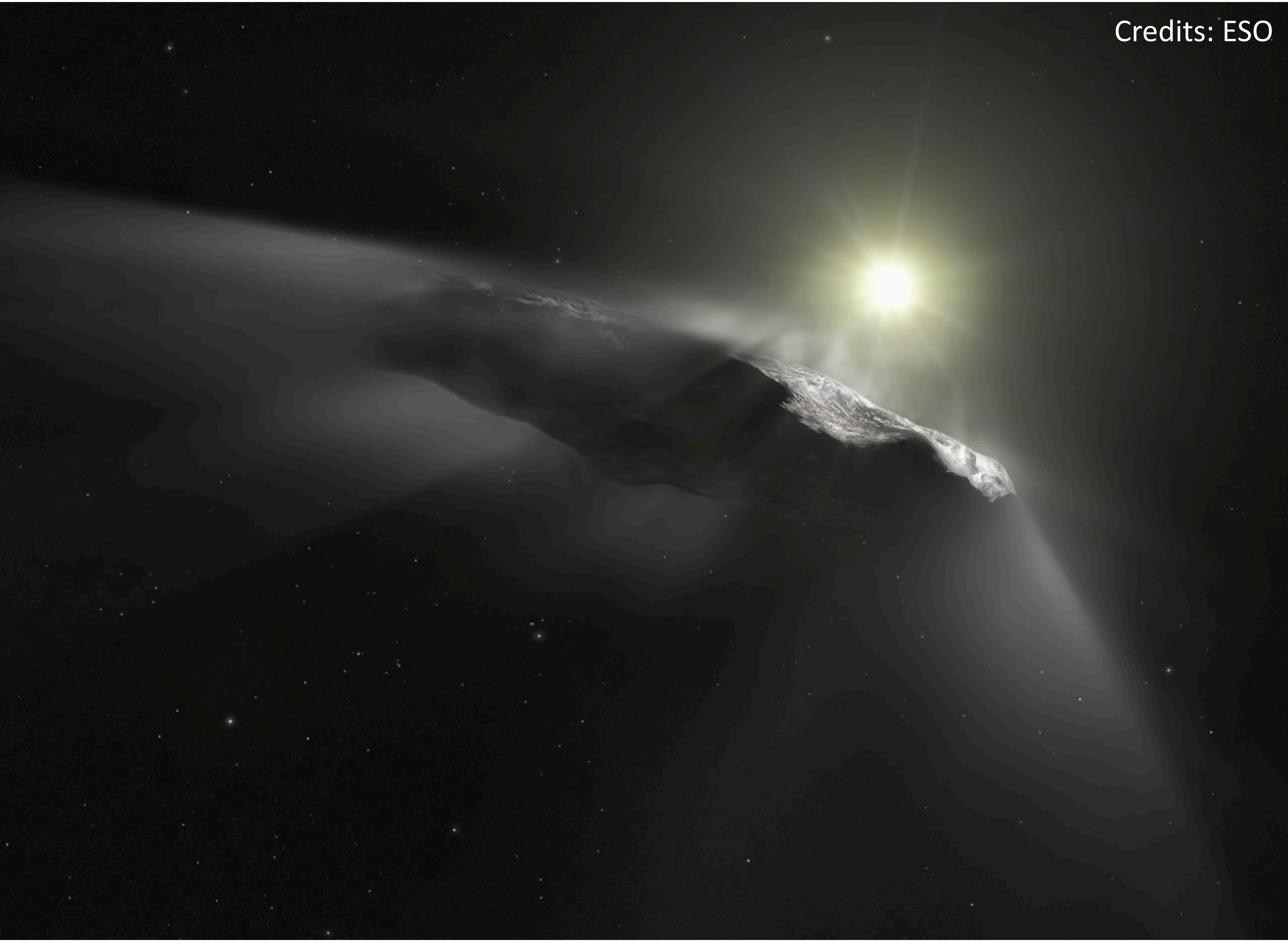
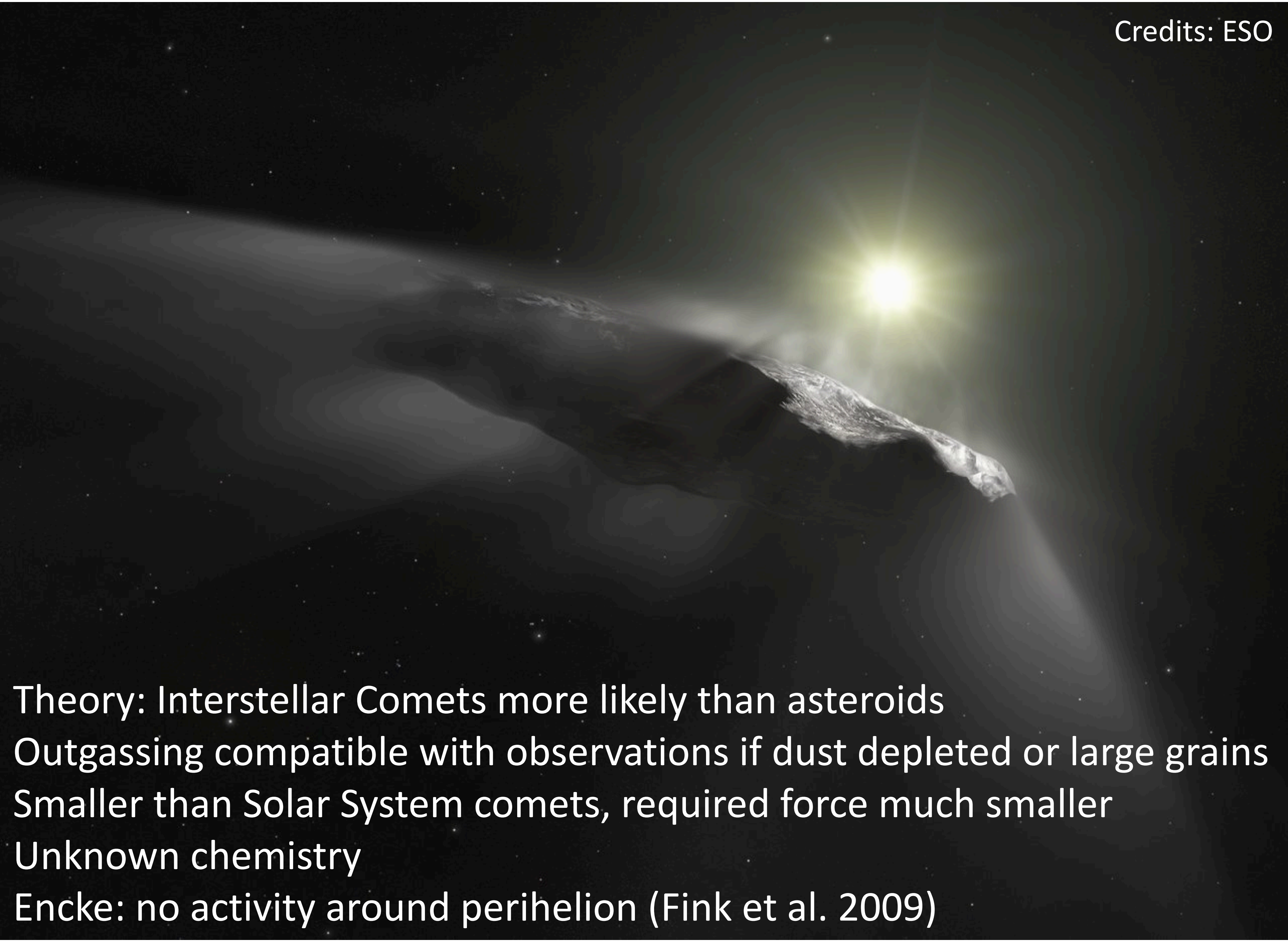




Micheli et al. 2018


Credits: ESO



Theory: Interstellar Comets more likely than asteroids

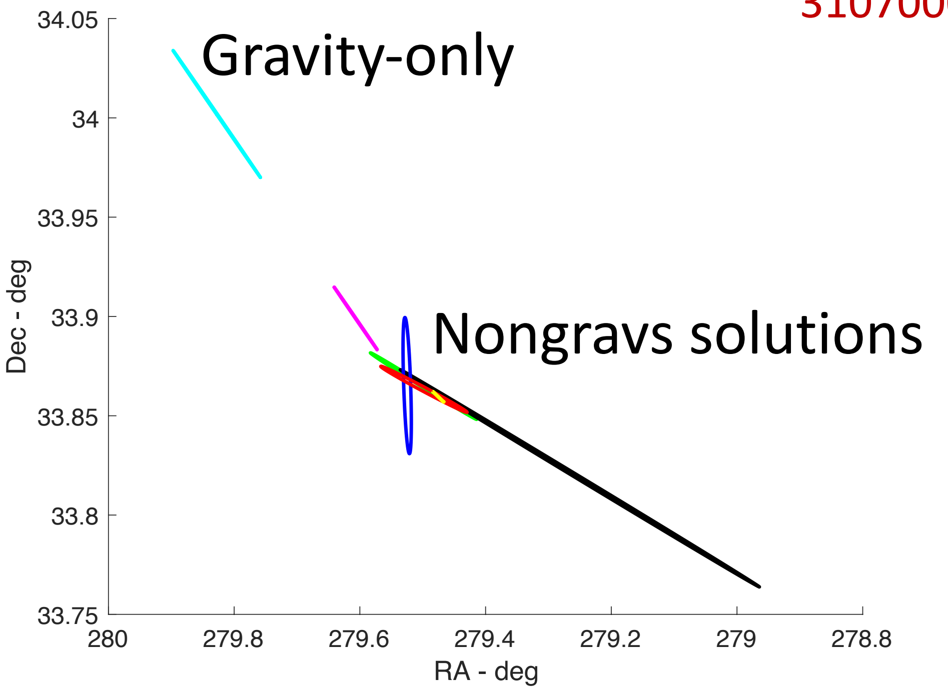
Outgassing compatible with observations if dust depleted or large grains

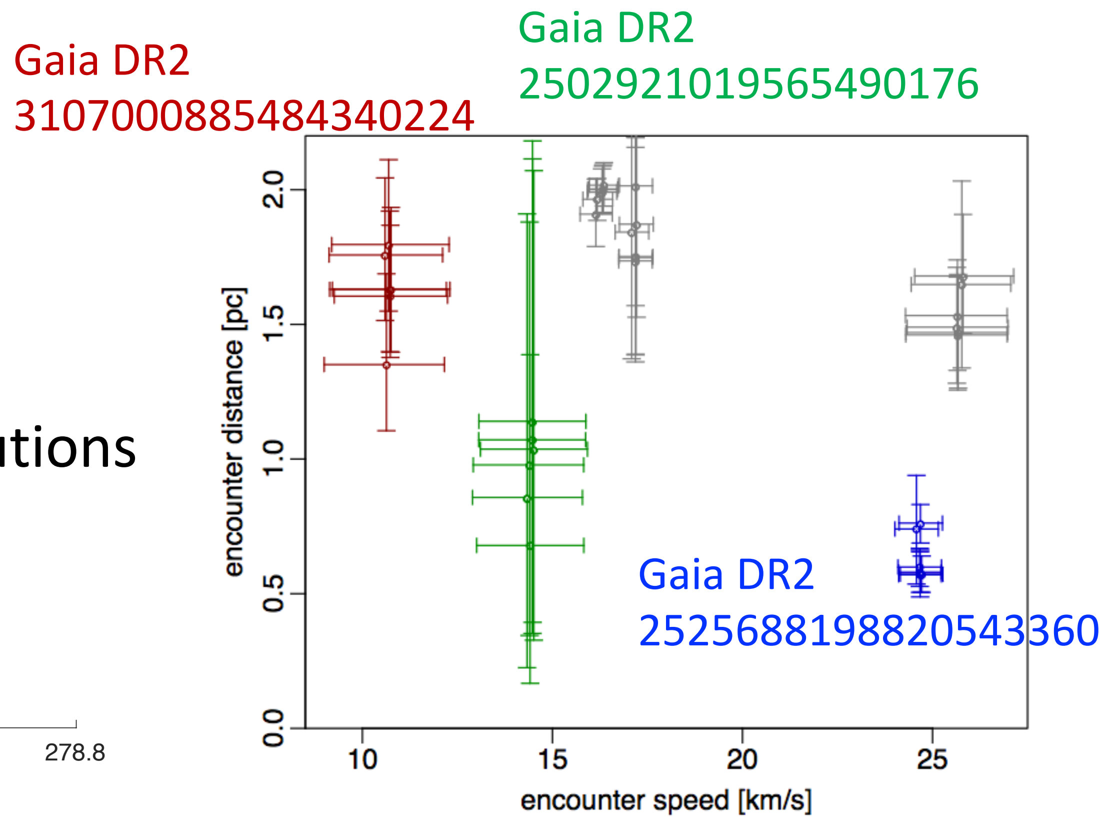
Smaller than Solar System comets, required force much smaller

Unknown chemistry

Encke: no activity around perihelion (Fink et al. 2009)

Where did it come from?





Bayler-Jones et al. 2018

Next one?

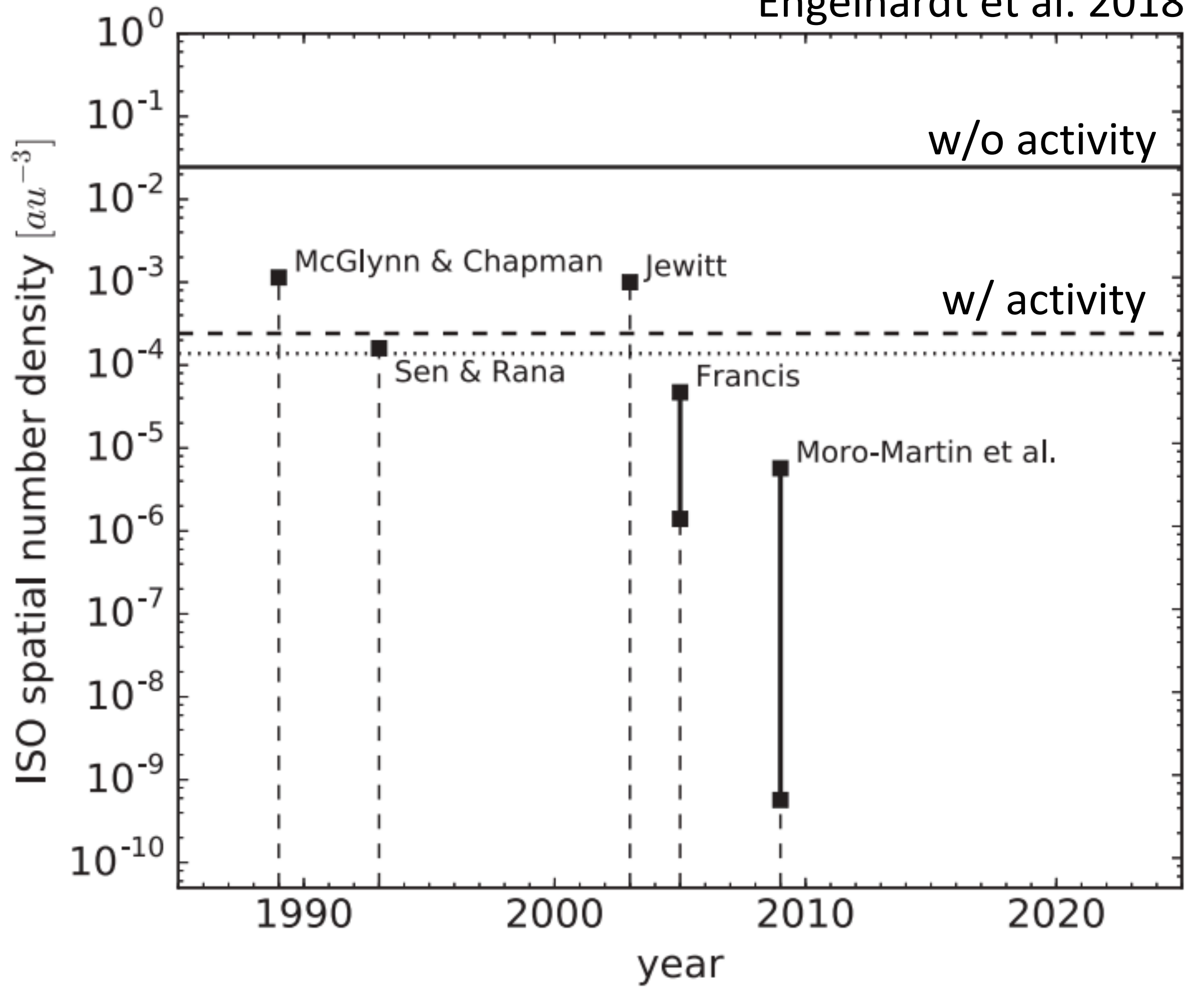
One in 20 years of NEO surveys.

Impact parameter \`Oumuamua 0.8 au. Scale quadratically.

90% confidence upper bound w/o activity: ~ 1 object within 1 au of the Sun at any given time.

Be ready for physical observations!

Engelhardt et al. 2018



Farnocchia, Tommei, Milani, Rossi 2010